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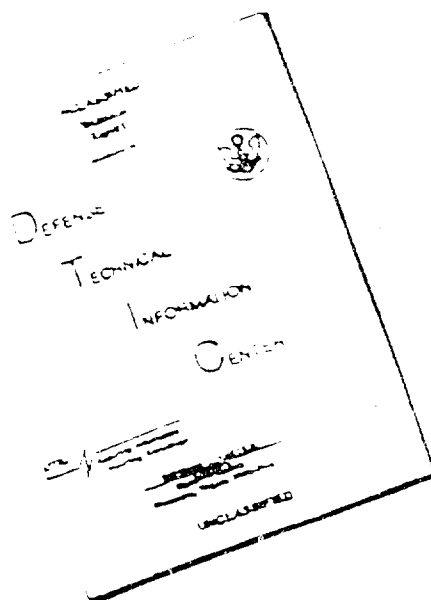
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This report presents the final results of studies to obtain baseline data about human target acquisition performance. Factors considered crucial to the acquisition problem were varied parametrically while others were held constant. The results are reported in five major phases corresponding to organization of the investigation into particular areas of concentration. All studies were performed in Martin Marietta's Guidance Development Center (GDC) in Orlando, Florida.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Targets						
Simulation						
Detection/Recognition						
Color vs Monochrome TV						
Target Acquisition						
Fields of View						

TARGET ACQUISITION STUDIES
(Final Report)

OR 11,901   April 1972

Frank D. Fowler
Dr. Daniel B. Jones

Contract No. N00014-67-C-0340
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Engineering Psychology Branch
Office of Naval Research
Washington, D.C.

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Orlando, Florida

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ABSTRACT

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ACKNOWLEDGEMENTS

1.0 INTRODUCTION AND SUMMARY

For the past five years, under the sponsorship of the Office of Naval Research (ONR), Martin Marietta has performed integrated studies of airborne observer target acquisition capability (References 1 through 5). The objectives were to obtain baseline data about human target acquisition. A step-by-step progression from simple to complex variables and crew tasks was employed. Factors that were felt to be crucial to the acquisition problem were varied parametrically while others were held constant for a particular experiment. The successful use of sensor/display systems, whether TV, infrared, or other devices, depends primarily on the ability of the observer to detect and recognize objects by the unaided eye viewing the target through the canopy and/or acquiring the target on the display. This target acquisition baseline data is needed by designers to help determine the limits placed on a particular system by the ability of the human visual channel to perform the requisite functions.

All of the studies were performed in the Martin Marietta Guidance Development Center (GDC) which contains a three-dimensional 600:1 scale terrain model, flight platform with simulated flight dynamics and the capability to view targets directly through a simulated cockpit window or on a closed circuit television monitor system (Figure 1).

Table I summarizes the five phases of the study program and the study emphasis for each phase. Research was begun as a psychophysical investigation of threshold visual acuity, and then expanded into a parametric study of many factors including brightness, contrast, target dimensionality, television fields of view (FOV), television system characteristics, and pilot briefing and search requirements. Each study is briefly described below:

Contrast – For both television and direct vision mediated viewing, brightness contrast was a critical parameter. For television, at contrasts of 25 percent or less, acquisition range and subject variability were directly proportional to contrast (i.e., range and performance decreased as contrast decreased). Direct viewing performance continued to improve with higher levels of contrast. For contrasts of 5 to 15 percent, large decrements and variances in performance were obtained regardless of search mode or degree of briefing.

Field of View – Dependence on contrast decreased with increasing FOV since maximum exposure time (the time interval between target detectable threshold and passage from the display FOV) was decreasing. At wide FOV's, exposure time was so short that targets were detected quickly, regardless of contrast, or not detected at all.

Direct versus Television Mediated Viewing – To detect the same size target at equivalent ranges, the television system (using a typical 525 line monitor) must display a target size 2.5 to 5 times greater than that required under direct view conditions.

0

Contrast Enhancement – For positive contrast targets (targets having less brightness than their backgrounds) higher television system gamma values (dynamic grey scale) resulted in improved detection.

Direct View to Display Transitioning – Pilots consistently detected and recognized targets through the canopy before they could detect targets on their display. Pilots required an average of 20 seconds to find the target on the display after initial direct visual detection.

Color versus Monochrome Television – Color television displays did not enhance the ability of the pilots to detect or recognize targets over standard black and white displays.
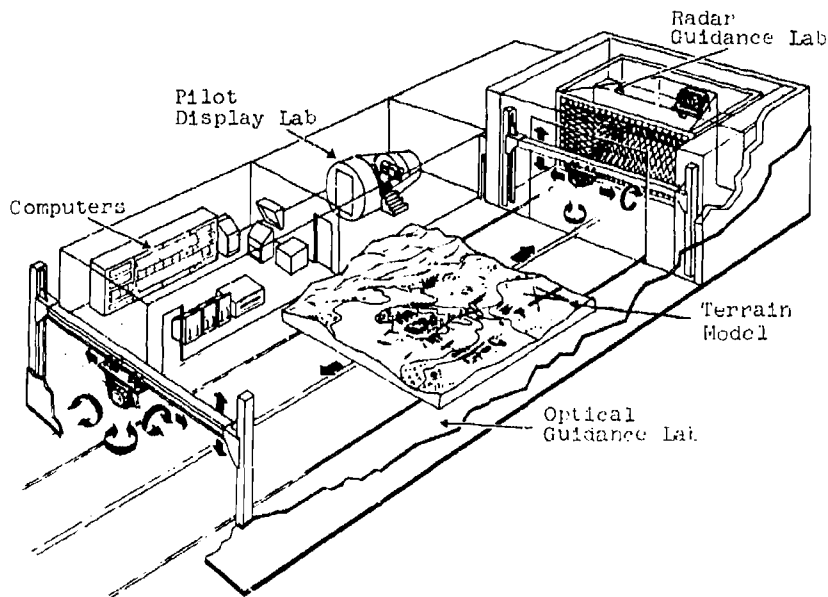

Figure 1. Guidance Development Center

TABLE I

Summary of Target Acquisition Studies

	Program Phases												
	I		II			III		IV			V			
Study Emphasis	TV Search, Detection & Recognition		Visual Search, Detection & Recognition	Visual Detection & Recognition Thresholds		TV Detection & Recognition Thresholds		2-D vs 3-D Targets		TV Gamma Effects	Visual-to-TV Transition		Color vs Monochrome TV	
Test Identification	1a	1b	1	2a,b	2c,d	1a,b	1c,d	1a	1b	2	1a	1b	2a	2b
Operator Tasks & Independent Variables														
● Viewing Mode														
(1) Direct Visual			X	X	y			X		✦	(X)		(X)(6)	
(2) Monochrome (B&W) TV	X	X				X	X		X	X		X		X
(3) Color TV														
● Scene Dynamics (Range Closure)														
(1) Continuous Convergence	X	X	X	(X		(X		X	X	X	X	X	X	X
(2) Static (Step) Convergence					λ)		X)							
● Operator Tasks														
(1) Target Search	X	X	X								X	X		
(2) Target Detection	X	X	X	X(1)	X	X	X	X	X	X	X	X	X	X
(3) Target Recognition	X	X	X	X(3)	X(3)	X(3)	X(3)	X	X	X	X	X	X	X
● Target Dimensionality and Type														
(1) 2-D Buildings	X	X	X	X	X	:	λ				X	X	X	X
(2) 3-D Buildings & Vehicles								X	(X | X)				
● Target Briefing (within prebriefed area)														
(1) Unbriefed location within viewed area	(X			X	X	λ	X	X	X	X		X	X	X
(2) Unbriefed location within viewed area		X)	X								X			
● TV Field-of-View (FOV)														
(1) Selected, fixed values for a given run	(X)	(X)				(X)	(X)					(X)	X	X
(2) Zoom(1)									X	X				
● Aim Point (TV)														
(1) Target offset from optical axis	X	X										X		
(2) Target on-axis (in central region of FOV)						X	X		X	X			X	X
● Target Area Background														
(1) Open	X	X	X	X	X	X	X		X	X	X	X	X	X
(2) Cluttered						X	X							
● Target/Background Discrimination Cues(2)														
(1) Brightness Contrast	(X)	(X)	(X)	(X)	(X)	(X)	(X)		(X)	(X)(4)	(X)		(X)	(X)
(2) Color Contrast											(X)		(X)	(X)

Legend: (X) and (XX) denotes primary inter- and intra-test variables

NOTES:
(1) Zoom lens programmed to simulate fixed FOV physical closure on targets at desired rates
(2) Primary cues in addition to size and form factor cues.
(3) Detection and recognition tests were performed on separate runs.
(4) TV displayed grey scale (and contrast) was varied by selecting different values of system gamma.
(5) Briefed by virtue of having prior direct visual location of the target.
(6) Color TV System used with chrominance channel switched off to produce monochrome display.

1B

2.0 COMMON TEST ITEMS/CONDITIONS

Principal items and conditions which were common to the various test phases are summarized below:

- GDC 600:1 scale terrain model — provided variety of target area types.

- Prebriefed target areas (within which target search, when required, was confined).

- Daylight target acquisition — Typical terrain model incident illumination was 200 to 400 fc.

- Stationary target types only.

- Target/background brightness contrasts:

  1 Nominal range from 10 to 40 percent;

  2 Extreme range from 5 to 50 percent;

  3 All targets were darker than their backgrounds.

- Accurate target/background brightness contrast control achieved using two-dimensional targets and balanced GDC lighting:

  1 Simulated flight conditions were 350 knots approach velocity at 3,000 feet altitude (achieved either by physical closure on targets or by simulated closure using television zoom lens).

  2 Television displayed image movements resulted from scene expansion with range closure (no significant translatory scene motions).

- In static tests — Used step type physical closure on targets.

- Experienced pilot subjects.

- In direct visual tests:

  1 Subject was seated on observer platform (simulated cockpit) overlooking terrain model.

  2 Observer platform attached to transverse carriage, and vertical movement I-beam was positioned to produce desired viewing geometry for each target run.

- In television mediated tests:

  Television camera was mounted on 3-axis gimbal assembly. As in the direct viewed case, positioning of the transverse carriage and I-beam established proper television viewing geometry for each target run.

- Analog computer-controlled functions included:

  1 For direct visual and fixed FOV television tests:

     a Terrain model longitudinal drive movement (range closure).

     b Television camera pitch angle position to maintain accurate aiming at center of target area during range closure.

     c Television optical focus during range closure.

2

<u>2</u> For television zoom lens-simulated range closure:

Zoom optics focal length.

● Television equipment operating characteristics (see Table II).

● Television display viewing conditions:

<u>1</u> Operator-to-display viewing distance — 18 inches (nominal).

<u>2</u> Display was arranged to eliminate direct reflections on faceplate from ambient illumination sources.

TABLE II

Television Equipment Summary — Television Mediated Tests

Item	Phase I Test 1a + 1b	Phase III Test 1a - 1d	Phase IV Test 1b + 2	Phase V Test 1a + 1b	Test 2a + 2b
Camera type	Cohu 2000 series (monochrome)	Same as Phase I	Same as Phase I	Same as Phase I	IVC Model 300A (color)
Display type	Conrac CNB 8 (monochrome)		Conrac CZB 8 [2]		SONY CBM-1200UA (color)
Display size	8" diagonal		Same as Phase I		12' diagonal
Scan lines/frame	525, 2:1 interlaced				Same as Phase I
Frame/field rates	30/60 per second				
Scan aspect ratio	3:4				
System limiting horizontal resolution (nominal)[1]	500 TV lines				300 TV lines [3]
Display highlight brightness (nominal)	100 to 200 fl		20 to 40 fl		50 to 100 fl (est.)
Camera output video SN ratio (estimated)	Relatively low noise 30 to 40 dB (peak video/rms noise)		Same as Phase I		Same as Phase I
Displayed grey scale (nominal)	9 shades of grey ($\sqrt{2}$ steps)				

NOTES:

(1) Measured with standard black & white resolution chart

(2) Used in conjunction with a Martin Marietta-developed gamma control unit

(3) IVC camera video signals were recorded in the GDC and played back into the SONY display for subjective tests using an IVC Model 825 video tape recorder/reproducer.

3

3.0 PHASE I: FIXED TELEVISION FIELDS OF VIEW

Nature and General Scope

This operationally-oriented study investigated the capability of an air-crew member to acquire surface targets via television in air-to-surface search missions. A simulated altitude of 3000 feet and airspeed of 350 knots were common to all test runs. Operator tasks included dynamic search, detection, and recognition of single, two-dimensional building type targets located on relatively uncluttered backgrounds. Nominal target/background contrasts were 5, 10, 15, 20, 25 and 35 percent as measured on the monochrome television display. The simulated size of the targets was approximately 62 feet long and 31 feet high. Four television camera fields-of-view (FOV) were employed – 4.9, 7.3, 9.7, and 14.5 degrees in the horizontal dimension. The targets were positioned in prebriefed, one-half mile square areas on the terrain model. Several target crossrange/downrange offsets from the center of the prebriefed areas (the television aim points) were employed (viz., 360/270, 950/540, and 2200/1800 feet). The tests were divided between briefed and unbriefed target positions within these areas.

Study Objectives

The primary objectives of the study were to:

1   Determine the effect of different television FOV's on operator performance.

2   Determine the effect of contrast on visual requirements for target detection and recognition.

3   Determine the effect of target briefing on operator search time requirements.

Results

Performance was not uniformly dependent upon contrast. Other contributing factors were search time, detection and recognition criteria (operator decision time), field-of-view, and the nature of the visual cues. Figure 2 shows average range performance in the unbriefed mode as a function of contrast for the two smaller FOV's (combined) and the two larger FOV's (also combined). Test results showed decreasing dependence on contrast with increasing FOV, since maximum exposure time (time between the target reaching detectable threshold and loss from the FOV) was decreasing. The exposure time at the widest FOV was so short that the target either was detected very quickly, regardless of contrast, or was not detected at all. In the briefed mode, however, the target position was known relative to grosser terrain features, and acquisition range was dependent on contrast for all FOV's. As shown in Figure 2, recognition was highly correlated with detection. Once detection occurred, recognition was principally a matter of waiting for the target image to grow to sufficient size. Although unbriefed target detection ranges were smaller than for corresponding briefed targets, recognition

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occurred at approximately the same ranges for both briefing modes. Probability of detection was strongly contrast-dependent for both briefed and unbriefed targets. However, as shown in Figure 3, higher probabilities were obtained in the briefed mode for a given contrast level. As shown in Figure 4, probability of detection was independent of FOV in the briefed mode, but decreased with increasing FOV in the unbriefed mode, apparently due to decreasing exposure times. Two types of search were involved in these tests. In briefed mode missions the search was for large visual cues such as roads, rivers, etc., in order to find the expected target location within the total pre-briefed area. This area search required approximately 24 seconds independent of FOV. However, the operator still had to wait for the target size to reach the detection threshold, which could significantly increase the mean time to detection, depending upon FOV and target contrast. In the unbriefed mode the mean time to detection exceeded the briefed mode by an average of 12 seconds due to additional search requirements. Figure 5 is a representative plot of mean time to detection as a function of FOV for the unbriefed mode.
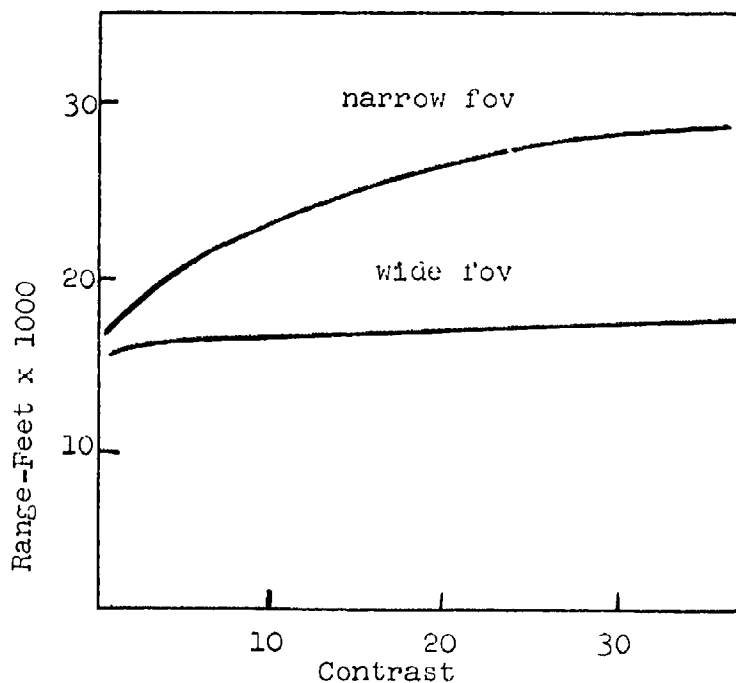

Figure 2. Detection for Unbriefed Search As
a Function of Contrast: Wide and Narrow FOV.

ag modes. Probability
afed and unbriefed
ties were obtained
in Figure 4, proba-
mode, but decreased
to decreasing ex-
tests. In briefed
s roads, rivers,
a the total pre-
seconds independent
target size to
increase the mean
. In the unbriefed
by an average of
5 is a representa-
for the unbriefed

o Unbriefed
o Briefed

Contrast ~ percent
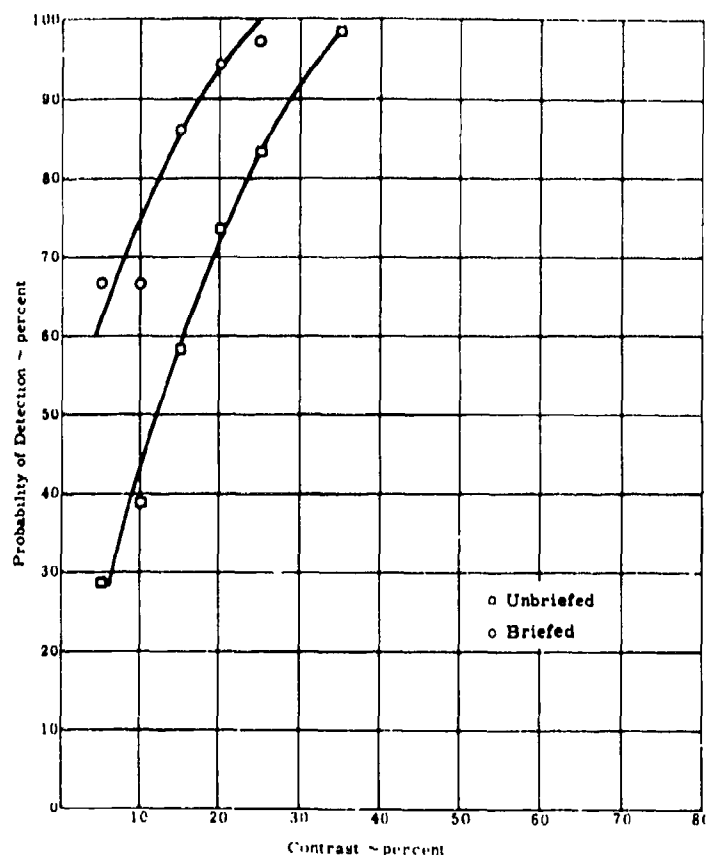
Figure 4. Probability of Detection
Averaged Over Contrast

Figure 3. Probability of
Averaged Over Field-
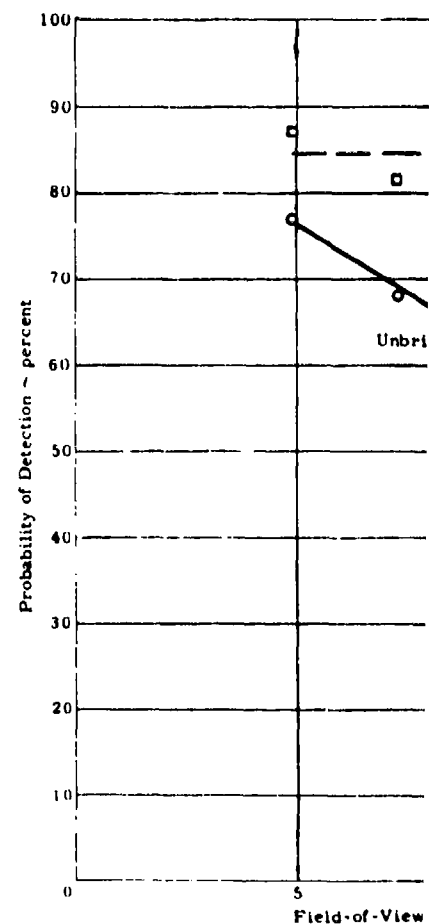
Unbri

Field-of-View

As
POV.

4 B

Figure 3. Probability of Detection
Averaged Over Field-of-View

Field-of-View ~ degrees

○ Computed from Range Data - 50% Distribution Point
△ Computed from Visual Angle Data - 50% Distribution Point
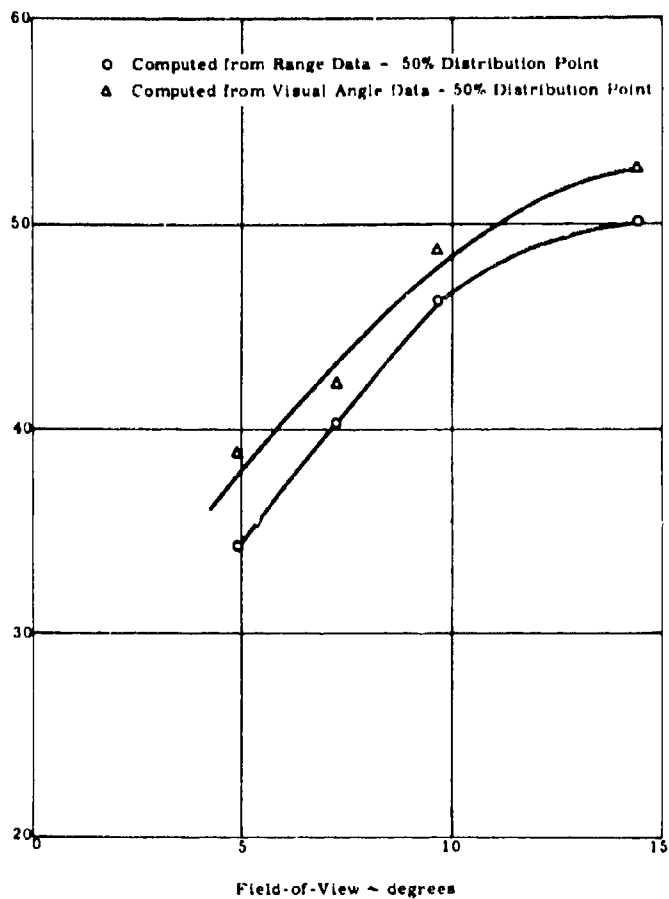
Time ~ seconds
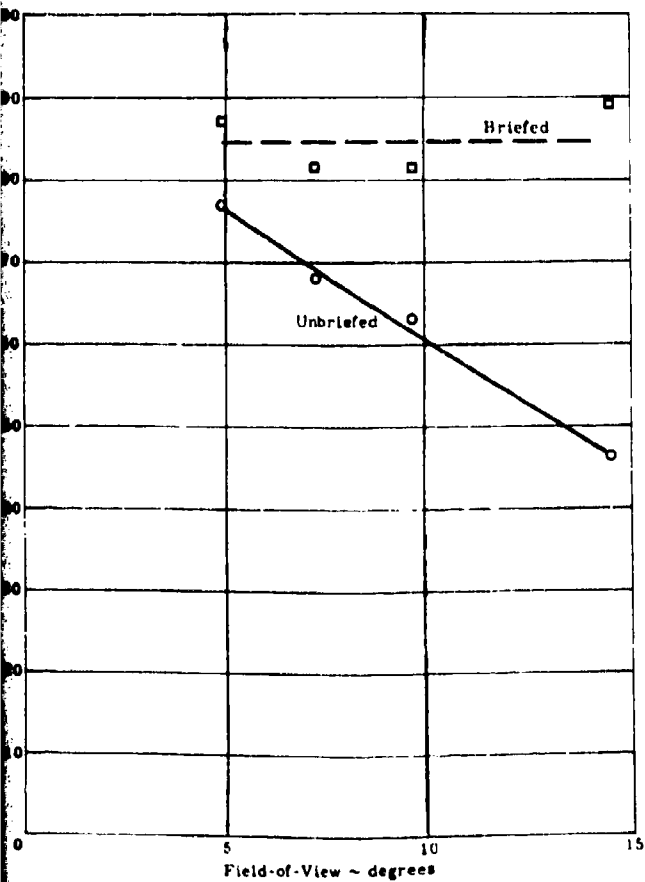
Field-of-View ~ degrees

Figure 5. Mean Time to Detection
(Unbriefed Mode)

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4.0 PHASE II: VISUAL ANGLE REQUIREMENTS FOR DIRECTLY VIEWED TARGETS

Nature and General Scope

This study investigated target acquisition performance for directly viewed targets. In all, five tests were designed and conducted to determine an operator's target detection and recognition capability. The first test was operationally-oriented and could be considered the direct visual counterpart to the unbriefed Phase I television acquisition tests. The subjects were required to search prebriefed one-half mile square terrain model areas under simulated dynamic flight conditions, and detect and recognize two-dimensional building-type targets located at unbriefed positions in these areas. Target/background contrasts ranged from 5 to 50 percent. The remaining four tests were designed to establish the psychophysical thresholds for both detection and recognition of two-dimensional building targets at briefed positions on the terrain model. This was done for cases under both static and simulated dynamic flight conditions. The targets were located on uncluttered backgrounds and the target/background contrasts ranged from 5 to 50 percent.

Study Objectives

The primary objectives of the study were to:

1   Determine the effect of contrast on visual angle and range requirements for dynamic target search, detection, and recognition under direct viewing conditions.

2   Determine the effect of contrast on visual angle requirements for both threshold detection and threshold recognition of prebriefed targets under static and dynamic conditions.

Results

In the detection mode, substantial differences in operator performance between the dynamic search task and the related threshold (prebriefed) task are shown in Figure 6. This condition held over the entire range of contrasts. There was a reasonably consistent difference between detection and recognition performance in the search mode over this range of contrasts. For the recognition tasks – search versus threshold – target contrast appeared to mask the effects of search, producing relatively small differences between the search and threshold visual angle requirements until the contrast level reached the 20 to 25 percent range (Figure 6). Corresponding detection and recognition ranges for the search and threshold tasks are shown in Figure 7. These ranges are calculated, based on equal target sizes for the Phase I and Phase II tests, to provide a common basis for comparison of operator performance. In the threshold test series no statistically significant differences were found in operator performance between the static and dynamic conditions.
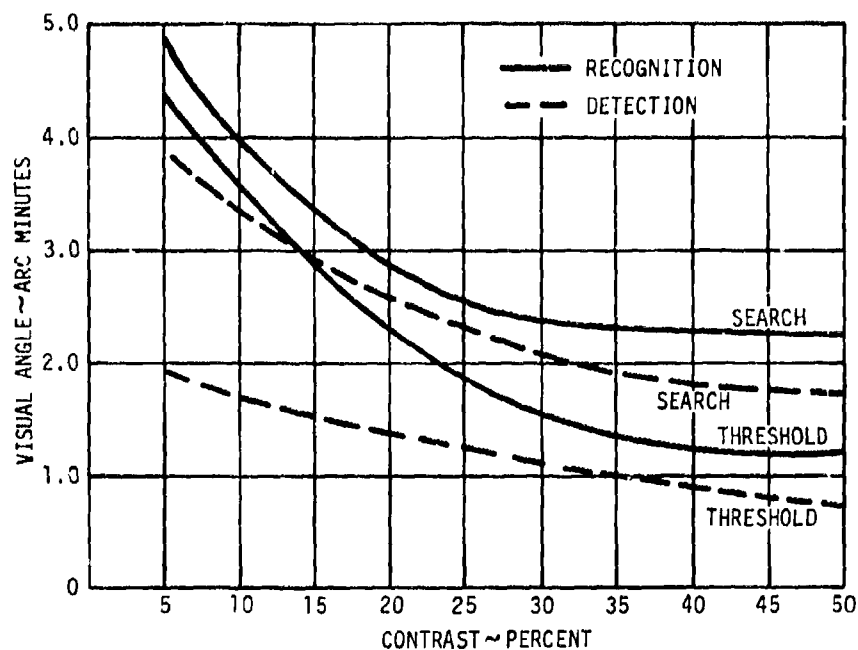
Figure 6. Visual Angle as a Function of
Contrast for Detection and
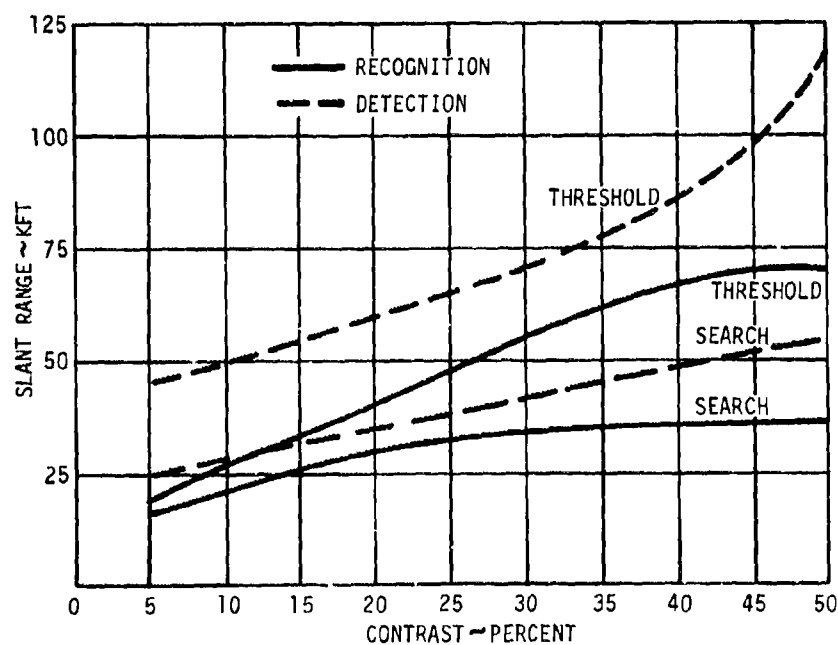Recognition in Dynamic Search
and Threshold Tasks

Figure 7. Slant Range as a Function of
Contrast for Detection and
Recognition in Dynamic Search and
Threshold Tasks

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5.0 PHASE III: VISUAL ANGLE REQUIREMENTS FOR TELEVISION DISPLAYED TARGETS

Nature and General Scope

This study was designed as the television oriented equivalent of the direct vision threshold experiments. Detection and recognition of targets at briefed target locations were studied. Target-to-background contrast, television field-of-view, flight speed and target area background were controlled. Two-dimensional targets (silhouettes of three simple building shapes) were used to maintain a consistent brightness across the surface. Contrast values were 10, 25, 35, and 50 percent. Two FOVs were used — 7.3 and 14.5 degrees. Target areas were selected having background detail in proximity to the target as well as having completely open areas. Four individual tests were employed and consisted of target detection thresholds for displayed targets in dynamic and static modes, and recognition thresholds in dynamic and static modes.

Study Objectives

The study objective was to:

1 Determine the smallest visual angle that an object viewed on a television display could subtend at the observor's eye and be detected or recognized as a target.

Results

No differences were obtained between static and dynamic conditions for either 7.3 or 14.5 degrees FOV for the detection mode. That is, the subjects were unable to perform significantly better when they had unlimited viewing time than when they performed at the simulated 350 knot — 3,000 foot altitude approach conditions (see Figure 8). Visual angle requirements for the narrow FOV (7.3) were approximately 1.5 to 2 times greater than for the wide FOV. This was compensated for by the higher magnification power of the narrow lens, however, and still resulted in detection at a greater range. More targets were also detected with the 7.3 degree lens than for the wide FOV, and in approximately one-half the viewing time. For acquisition tasks in which the target is within the FOV of the display, a direct relationship to FOV was seen. That is, detection occurred in one-half the time and at twice the range for the 7.3 degree FOV than it did for the 14.5 degree FOV. The additional improvement was the (average) 5 percent fewer missed targets obtained with the smaller FOV.

As seen in Figure 9, a wider range of performance was obtained for the recognition tasks under both FOV conditions; although the superiority of the 7.3 degree FOV held, the major difference was that subjects performed significantly better with unlimited viewing time for the 14.5 degree FOV.
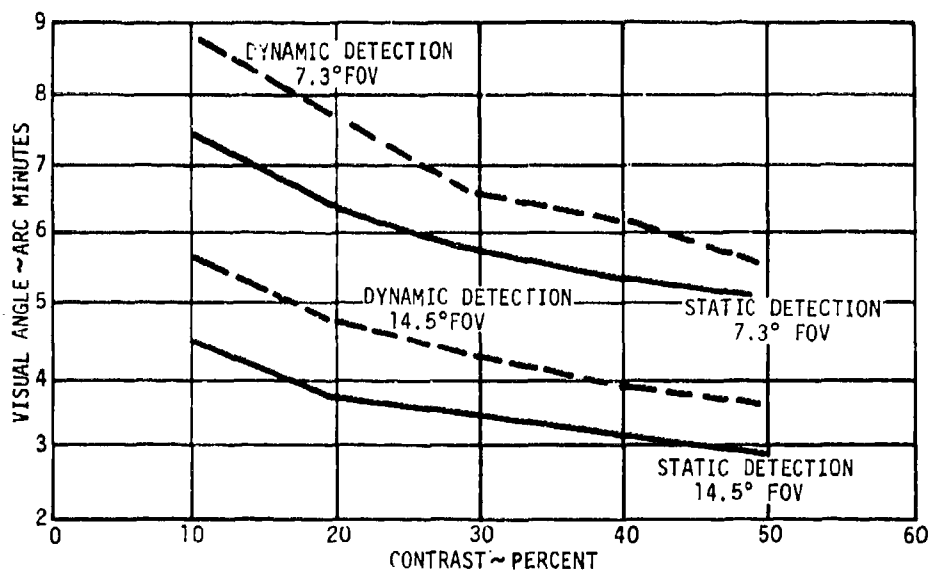
Figure 8. Detec   n as a Function of Contrast
for Dynamic and Static Viewing Conditions
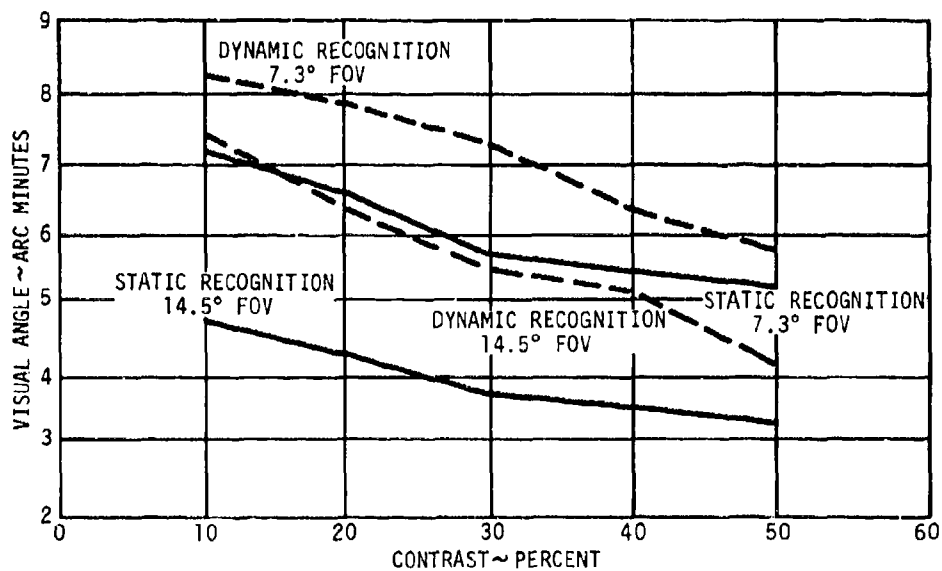

Figure 9. Recognition as a Function of Contrast
for Dynamic and Static Viewing Conditions

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6.0 PHASE IV: 2-D VERSUS 3-D TARGETS, AND TV GAMMA EFFECTS

Study I: Two-Dimensional Versus Three-Dimensional Targets

Nature and General Scope

Study I consisted of two separate tests which utilized three-dimensional targets and included detection and recognition tasks, under different combinations of detailed and non-detailed target types and target/background contrasts. Test A was done with the unaided eye, Test B with a television display. No data was gathered in Test A on two-dimensional targets because of the high similarity of previous tests utilizing unaided eye viewing conditions. The data in Study II which was taken with a normal gamma of 1 is directly comparable to the television mediated three-dimensional target data gathered in Study I.

Study Objectives

The study objectives were to:

1 Determine the effect of target dimensionality on detection and recognition performance.

2 Determine detection and recognition performance differences between detailed and non-detailed targets.

Results

Test A: Direct Visual — No difference in performance utilizing three-dimensional targets could be attributed to differences in contrast that were not also characteristics of two-dimensional targets (Figure 10). The vehicle targets were paired with building targets in order to match them for form-factor. No differences in performance with respect to this ordering was found, nor were differences found between any of the target pairs. However, there were differences in the recognition task, due to the use of gross or fine discrimination (building or vehicle), and these results are not directly comparable to two-dimensional targets. After detection, subjects had to decide whether the target was a building or vehicle, and then determine the type (left or right shed, house, truck, tank, or house), resulting in a two-level recognition task.

Test B: TV Mediated Tests — The results using television detection were similar to those using direct vision in that there were no differences between two-dimensional and three-dimensional targets. As mentioned in the results of Test A, the two-level recognition task utilizing gross and fine discrimination affected the results.

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Study II: Changes in Gamma for Television Displayed Targets

Nature and General Scope

Study II utilized two-dimensional building-type targets presented at three gamma levels (.55, 1.0, and 2.2) and three contrast values grouped into low, medium, and high ranges.   The tasks were both detection and recognition.

Study Objective

The study objective was to:

!   Investigate the effects of varying the critical television display transfer characteristic, gamma.

Results

At the low contrast values (5 to 10 percent) for normal gamma (1.0) performance was significantly better than at the gamma level of 0.5 for both detection and recognition.   At the medium contrast values (15 to 25 percent) no significant differences were noted at any gamma level.   At the high contrast level, there was no difference between 1.0 and 2.2 gamma values for detection; however, there was a difference for the recognition task (Figures 11 and 12).   For higher contrast targets the data indicated that a higher gamma resulted in better recognition performance.   The trends in the data indicated that, for positive control targets (i.e., target brightness less than background brightness) a higher television gamma may enhance acquisition.
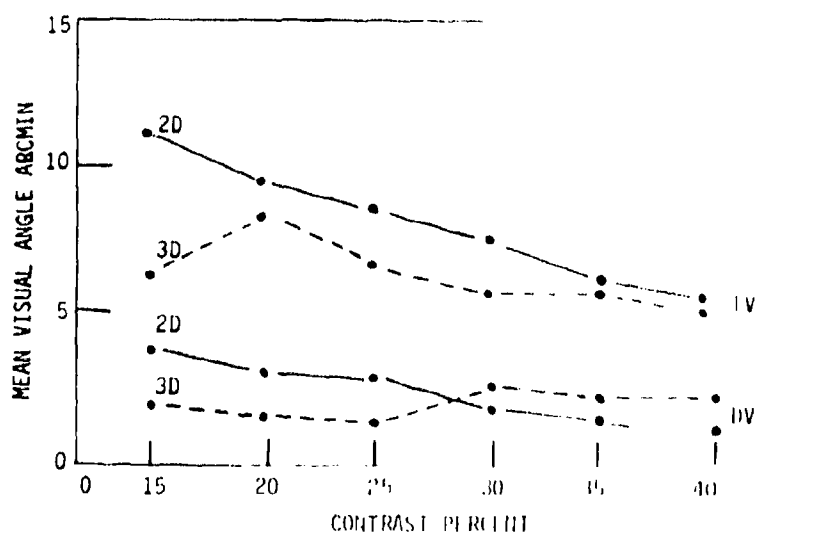

Figure 10.   Detection as a Function of
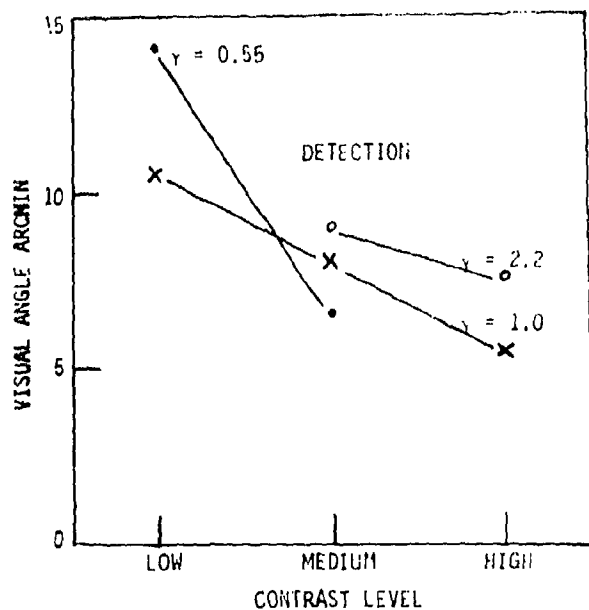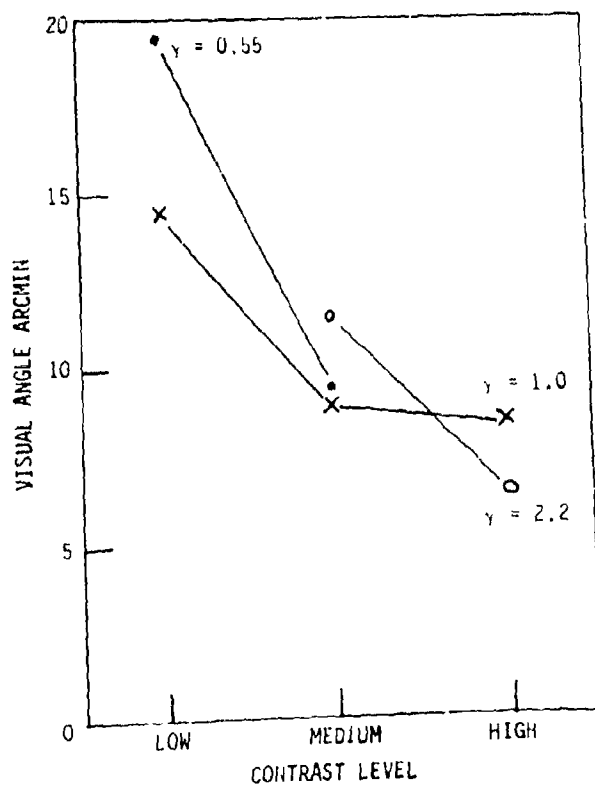Contrast for TV and Direct Vision

Figure 11. Effect of Gamma on Detection Performance as a Function of Contrast

Figure 12. Effect of Gamma on Recognition Performance as a Function of Contrast

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7.0 PHASE V: VISUAL TO TV TRANSITION, AND COLOR VERSUS MONOCHROME TV

Study I: Transition from Direct to TV Mediated Viewing

Nature and General Scope

Study I examined the task of finding a target displayed on a cockpit-mounted cathode ray tube (CRT) after the pilot had acquired it visually through the cockpit canopy. The two-dimensional targets were located in prebriefed, square target areas, one-half mile on a side. The flight path was held constant and extended to the center of the target area while the targets were offset from this flight line. The television camera tracked to the center of the target area and always presented this prebriefed area centered on the television monitor. The tasks (detection and recognition) used three television camera FOVs (4.8, 9.6, and 14.5 degrees) and eight target areas.

Study Objective

The study objective was to:

1 Measure the pilot's ability to make a transition to an on-board display and reacquire a target he had acquired visually.

Results

Pilots consistently detected and recognized the target viewed through the simulated windscreen before detection on the television (Figure 13). The direct viewing task produced greater subject variability than did the television mediated task. The major influence on detection appeared to be brightness contrast of the target. The narrow FOV (4.8 degrees) provided greater detection ranges than did the wider FOVs (see Figure 1), however, the detection probabilities were significantly lower in the narrow FOV case. The limitations of an on-board television display (in terms of resolution and image quality) are such that the pilot's principal acquisition mode is still direct visual.

Study II: Color versus Monochrome TV Displays

Nature and General Scope

Study II evaluated the differences in acquisition performance elicited by color and monochrome television display presentations of ground targets. Fourteen target areas were selected. Four target/background combinations were color mismatched, while ten were color matched (i.e., both target and background having the same basic color and differing only in brightness contrast). All target/background combinations were presented in color, and in black and white. Detection and recognition of the target were required for each trial.

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Study Objective

The study objective was to:

1 Determine whether the use of a color television system to mediate airborne target acquisition is superior to that of a black and white system.

Results

There was no difference between target acquisition performance using color and monochrome television displays (Figure 14). Also, within the color display mode, target/area combinations that were mismatched elicited performance similar to those with targets that were color-matched to their surroundings. At the relatively high contrast values which were used in this study, the use of a color display does not enhance target acquisition.
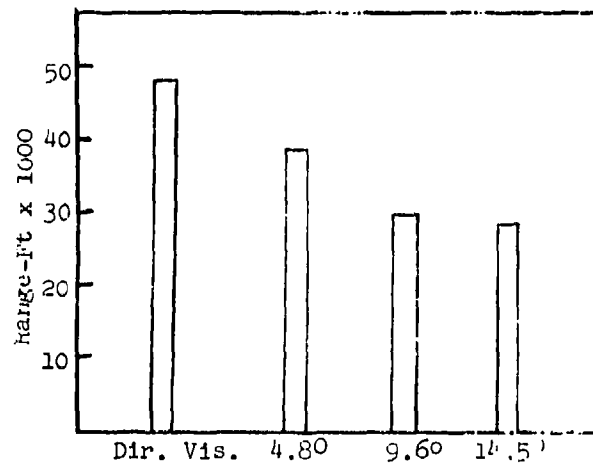

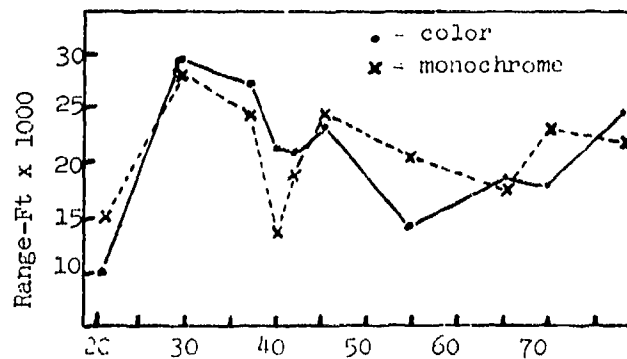Figure 13. Average Detection Range

Figure 14. Color Versus Monochrome as a Function of Contrast

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